



(12) **United States Patent**
Chutjian et al.

(10) **Patent No.:** **US 6,434,031 B2**
(45) **Date of Patent:** **Aug. 13, 2002**

- (54) **DRIVING A QUADRUPOLE MASS SPECTROMETER VIA AN ISOLATING STAGE**

- (52) **U.S. Cl.** 363/97; 363/25; 363/134;
250/292
- (58) **Field of Search** 363/97, 25, 134,
363/16; 250/292

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- (56)
- References Cited**

U.S. PATENT DOCUMENTS

- (73) Assignee: **California Institute of Technology,
Pasadena, CA (US)**

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| 5,426,578 | A | 6/1995 | Nakamura et al. | |
| 6,205,043 | B1 * | 3/2001 | Chutjian et al. | 363/97 |

- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 11 days.

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Primary Examiner—Kiet T. Nguyen

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- (21) Appl. No.: **09/813,654**

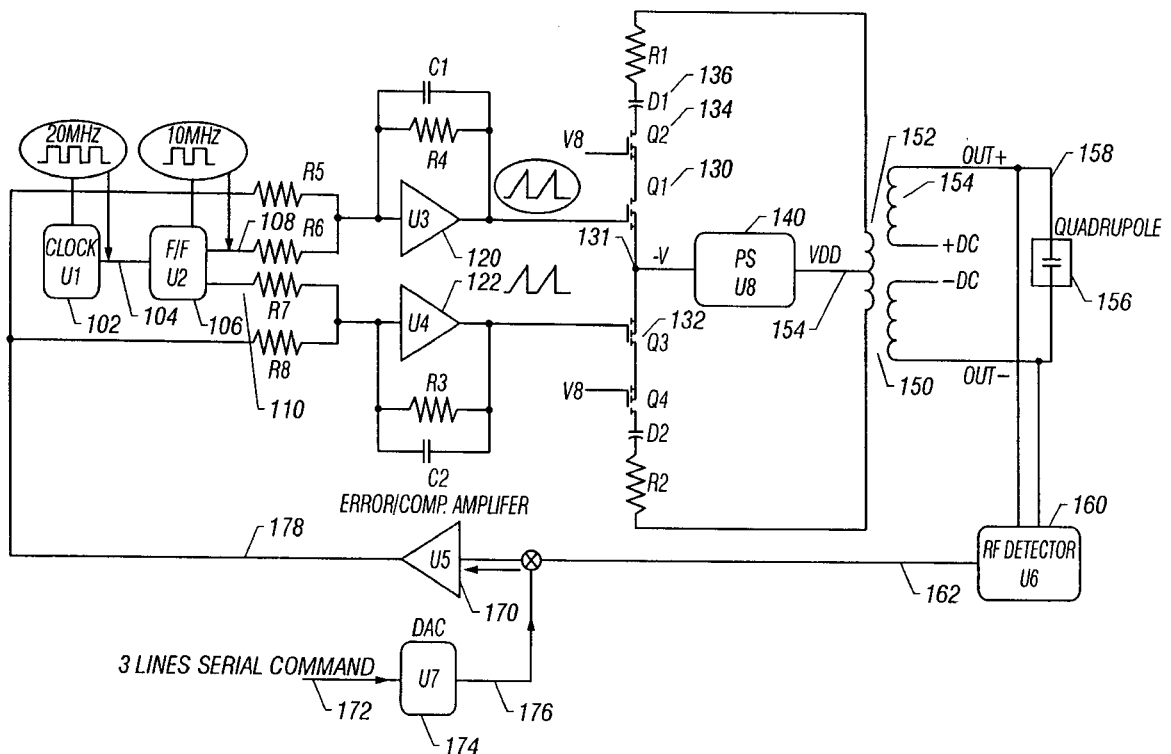
- (22) Filed: **Mar. 20, 2001**

Related U.S. Application Data

- (62) Division of application No. 09/392,351, filed on Sep. 8, 1999, now Pat. No. 6,205,043.
- (60) Provisional application No. 60/099,630, filed on Sep. 8, 1998.

- (51) **Int. Cl.⁷** **H01J 37/00**

6 Claims, 1 Drawing Sheet



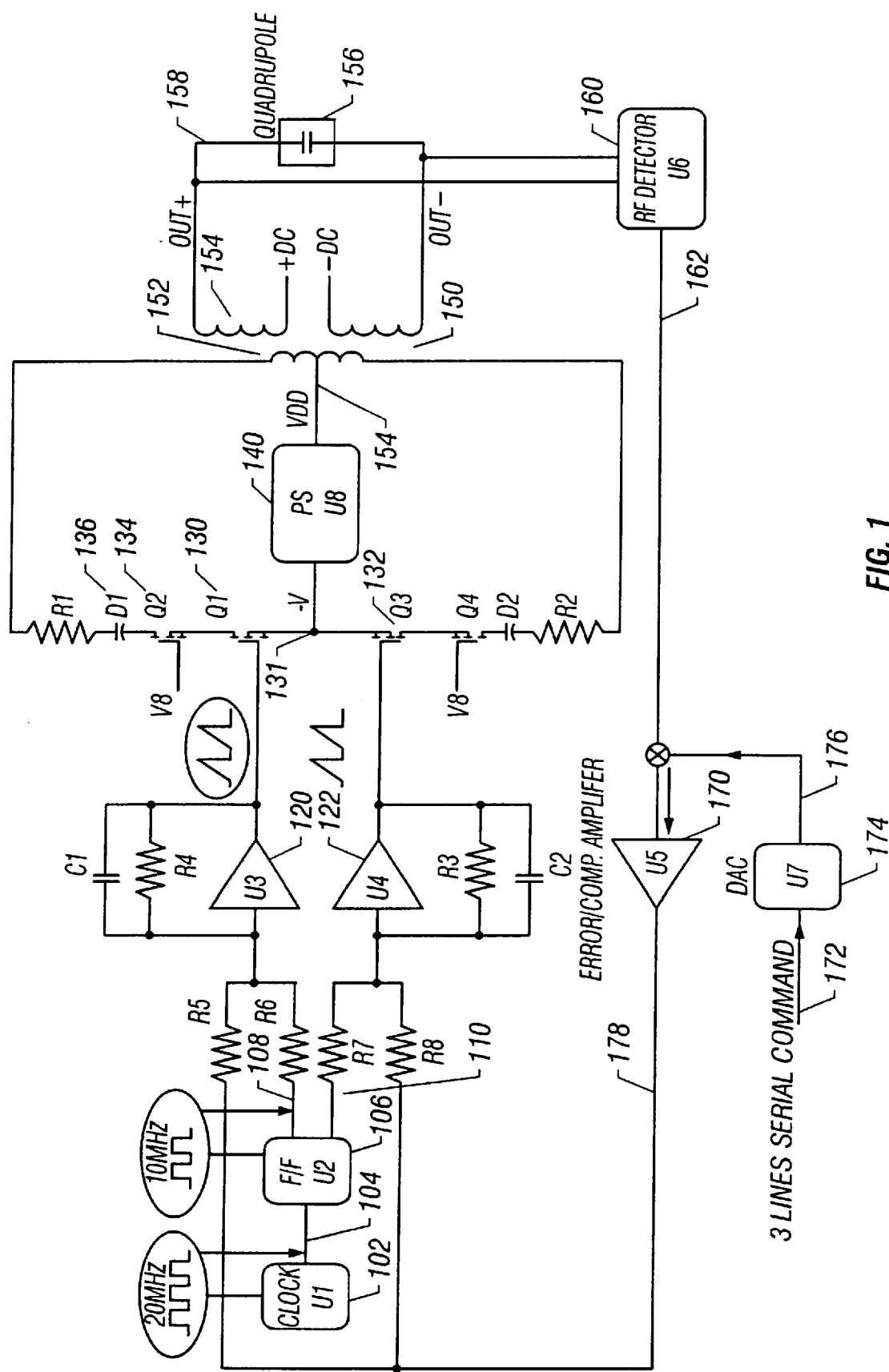


FIG. 1

DRIVING A QUADRUPOLE MASS SPECTROMETER VIA AN ISOLATING STAGE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. application Ser. No. 09/392,351, filed Sep. 8, 1999 (now U.S. Pat. No. 6,205,043 B1), which claims the benefit of U.S. Provisional Application No. 60/099,630, filed on Sep. 8, 1998.

STATEMENT AS TO FEDERALLY SPONSORED RESEARCH

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 U.S.C. 202) in which the Contractor has elected to retain title.

BACKGROUND

Certain applications, including a quadrupole mass spectrometer, can require a specialized power supply.

A power supply for this purpose has specialized requirements. It should be a high frequency power supply that has a variable peak RF amplitude, but is frequency and voltage stable once set. It should also be fully floating. These power supplies should also be capable of driving a primarily capacitive load.

If the device will be operating unattended or in space, the power supply should also be lightweight and efficient.

SUMMARY

The present disclosure teaches a stable, high amplitude, high frequency radio frequency and direct current power supply system. According to one aspect, the system uses a clocked operation to turn on power from a power supply.

A high dynamic range power supply is described that has an oscillator assembly operating from a first power supply and produce first and second out-of-phase, gradually increasing, signals, first and second transistors, coupled to receive said first and second signals respectively, and turned on by the signals to produce an oscillating output. The first transistor produces a first part of the oscillating output and the second transistor produces a second part of the oscillating output. A feedback loop has a detector sensing a level of the oscillating output and producing a signal indicative thereof. A second element compares that signal to a reference and produces an error output indicative of the difference, said error output causing a change in said first and second drive signals. The first transistor is referenced to a second power supply, having a different level than the first power supply.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic of the system.

DETAILED DESCRIPTION

The system is shown in detail in FIG. 1. A clock **102** produces a basic high frequency output **104**, here shown as a 20 megahertz clock. It should be understood that any other frequency could be used. A flip flop amplifier **106** divides the oscillating output **104** into two, out-of-phase 10 megahertz signals **108** and **110**. The in-phase 10 megahertz signal **108** is taken as a baseline (zero) phase shift, while the out-of-phase 10 MHz signal **110** is shifted by 180 degrees relative to signal **108**.

The output signals **108** and **110** are provided into two analogous, but out-of-phase circuits.

The integrator/summing amplifier **120** is shown as an operational amplifier with a capacitor **C1** and resistor **R4** in its feedback loop. This effectively changes the square wave output **108** into a gradually increasing signal such as a sawtooth shape having a similar frequency to the driving signal. The sawtooth frequency is applied to the gate of MOSFET **130**, and periodically turns on the MOSFET **130**. When MOSFET **130** is turned on, it drives current from the power supply **140** to one end of the primary **152** of an air core transformer **150**. The return for the power supply **140** is coupled to the center tap **154** of the air core transformer **150**. Use of a air core transformer can reduce the weight of the system.

MOSFET **130** begins conducting when the sawtooth level reaches the threshold voltage (V_{th}) of the MOSFET **130**. As the level of the sawtooth increases at the gate of MOSFET **130**, the conduction angle increases. As MOSFET **130** turns on more completely, it conducts more current. The phase-shifted signal **110** is analogously coupled through an amplifier **122** to an analogous MOSFET **132**. The two circuits operate similarly, but 180 degrees out-of-phase. When MOSFET **130** is in its active phase, MOSFET **132** is off. Conversely, when MOSFET **132** is in its active phase, the MOSFET **130** is off. In this way, the primary **152** of transformer **150** is being alternatively pushed and pulled from opposite directions by two out-of-phase 10 MHz signals. The output is therefore proportional to the amount of pushing and pulling that occurs.

The secondary **154** of transformer **150** is connected to a load **156** which can be a quadrupole mass spectrometer for example. If a quadrupole mass spectrometer is used, then the inductance of the air core transformer **150** can be adjusted to resonate with a capacitance of the analyzer. The inductance of T1 can be adjusted either mechanically or by changing the windings ratio of the transformer. Use of an air core transformer reduces the weight, and makes it feasible to use such a device. A transformer-coupled output ensures floating output.

The secondary **154** output is also connected to an RF detector **160** which produces a detection signal **162** with a DC level that is proportional to the amplitude of the RF signal **158** produced at the secondary **154** of the transformer **150**. The RF detector can include, for example, a rectifying diode. The RF detection signal **162** is coupled to one input of an error amplifier **170**. The other input of the error amplifier **170** receives a command **176** indicative of the desired RF level. A serial input command **172** is connected to digital to analog converter **174** which is converted to an analog level **176** indicating the desired level. This analog level **176** is coupled to the second input of error amplifier **170**.

The error amplifier **170** produces an error output **178** indicating the difference between the commanded level **172** and the actual level. This difference is coupled through resistors **R8** and **R5** to the input node of the respective sawtooth amplifiers **120** and **122** where it sums with the flip-flop outputs **108**, **110**. When the error amplifier output **178** is high, it increases the oscillation signal to a higher level, thereby increasing the drive to the input of the amplifier **120**. This effectively produces more conduction from the transistor **130**, thereby increasing the amplitude of the RF signal. The increased-amplitude RF signal is reflected by an increase in the output **162** of the RF detector **160**, which hence lowers the error signal **178**.

This control loop provides extremely stable RF and DC voltages. Hence, this system can be used for long term unattended operation in a changing external environment, such as in space or under highly variable temperatures.

An important feature of this circuit is its ability to obtain a large dynamic range output signal. At low levels, the drive signal can couple through the gate of the MOSFET, and generate an output signal which is much greater than the desired minimum signal. In fact, the desired minimum signal for a quadrupole mass analyzer is about that necessary to separate one atomic mass unit. In order to avoid the coupling-through operation, a cascade stage MOSFET **134** is placed in series with a diode **136**. The MOSFET is biased to bias level VB. This provides the isolation ot avoid the punch through phenomena noted above.

Another problem is based on the characteristics of operational amplifiers that are commonly used for this system. Most operational amplifiers have peak voltages of about 3 to 4 volts for the sawtooth wave produced by the amplifiers. This level might not be high enough to bias the available MOSFETs to drive enough power at the output levels. The peak voltage of the sawtooth is hence increased, by referencing the return of the main power supply to a negative voltage at node **131**. By so doing, the peak value seen by the MOSFET is increased by the level of the negative voltage present at the return of the driving power source.

Other embodiments are within the disclosed system.

What is claimed is:

1. A method of driving a quadrupole mass spectrometer, comprising:

obtaining an air core transformer with a primary and a secondary;

matching said secondary to the mass spectrometer; and driving the primary based on first and second voltage levels, said driving being via an isolating stage that minimizes low level drive signal coupling.

2. The method of claim 1 wherein matching the secondary to the mass spectrometer comprises adjusting an inductance of the air core transformer to resonate with a capacitance of the mass spectrometer.

3. The method of claim 1 wherein driving the primary based on first and second voltage levels comprises using a plurality of out-of-phase voltage signals to generate an oscillating signal that is applied to the primary.

4. The method of claim 1 wherein driving the primary based on first and second voltage levels comprises: splitting a high-frequency clock output into two out-of-phase voltage signals;

applying the two out-of-phase voltage signals to respective first and second transistors to produce an oscillating signal, wherein the first transistor produces a first part of the oscillating signal and the second transistor produces a second part of the oscillating signal; and applying the first and second parts of the oscillating signal to the primary.

5. The method of claim 1 wherein driving via an isolating stage comprises, prior to applying the first and second voltage levels to the primary, passing each of the first and second voltage levels through a cascade stage.

6. The method of claim 5 wherein the cascade stage comprises a cascade transistor in series with a diode.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,434,031 B2
DATED : August 13, 2002
INVENTOR(S) : Ara Chutjian et al.

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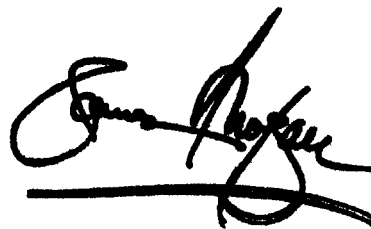
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page, showing the illustrative figure, should be deleted and substitute therefor, with the attached title page.

Drawings, sheet 1, Fig. 1, should be deleted and replaced with the attached page.

Signed and Sealed this

Ninth Day of September, 2003

A handwritten signature in black ink, appearing to read "James E. Rogan", written over a horizontal line.

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

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(73) **Assignee:** **California Institute of Technology**, Pasadena, CA (US)

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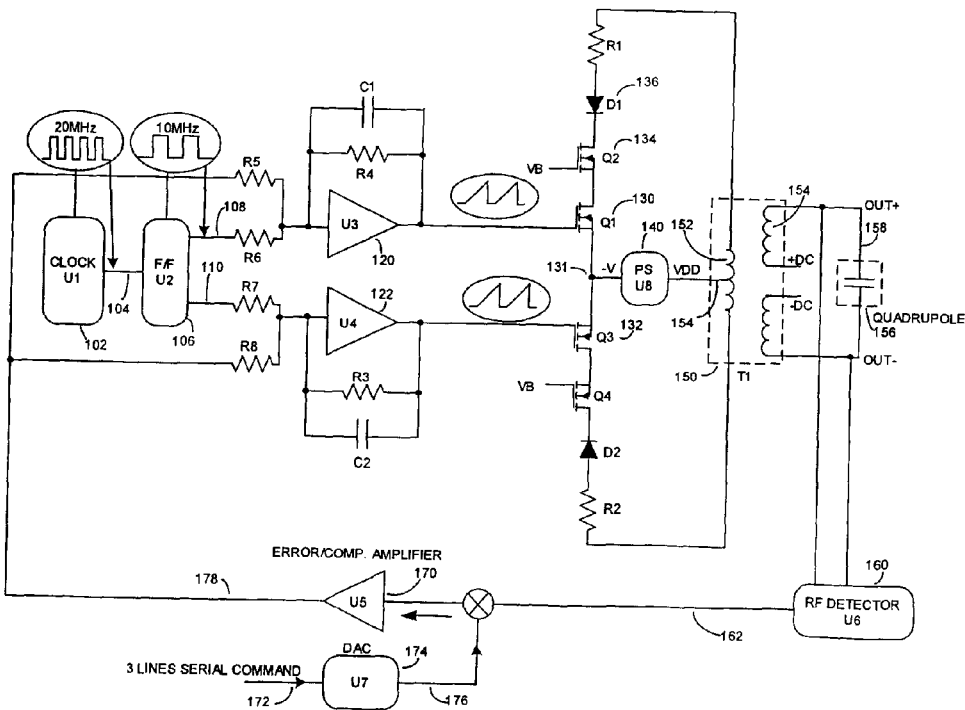
Primary Examiner—Kiet T. Nguyen

(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

Driving a quadrupole mass spectrometer includes obtaining an air core transformer with a primary and a secondary, matching the secondary to the mass spectrometer, and driving the primary based on first and second voltage levels. Driving of the primary is via an isolating stage that minimizes low level drive signal coupling.

6 Claims, 1 Drawing Sheet



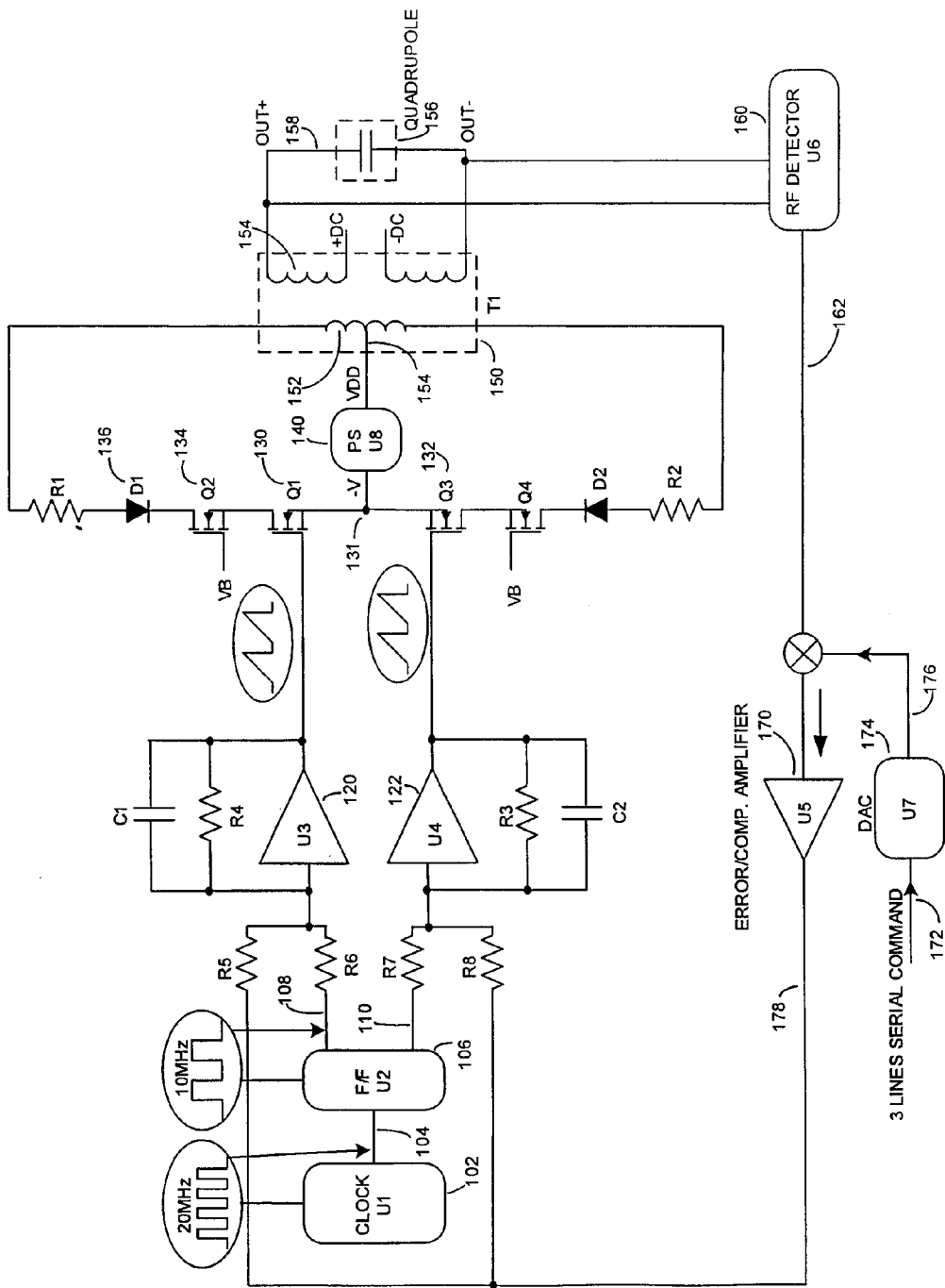


FIG. 1